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Press Shaping of Arched Components by Means of a Mobile Tool

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Abstract—The best tool motion in a press is considered, when producing U-shaped components from sheet. The elastoplastic properties of the deformed material are taken into account.

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The production of arched components of specified length on vertical presses employs a mobile tool, between the elements of which the metal sheet is placed. In particular, press shaping is used in the production of U-shaped blanks for the manufacture of longitudinal-seam welded large-diameter pipe (Fig. 1). The shape and dimensional precision of the products obtained in such equipment is determined by the stress–strain state of the metal in pressing. In investigating the deformation process, we must take account of the mutual motion of the executive elements—the punch and the beam—which are continuously in contact with the blank (metal sheet). In studying the kinematics of this interaction, we must note the presence of an intermediate elastoplastic element; the unsteady change in the sections of the part between the supporting rollers of the beam and its contact zone with the punch; and the geometric and physical nonlinearity, which determines the stress–strain state.

Our starting point here is to represent the blank–tool system as a coupled system of elements in a mechanism with an intermediate elastoplastic element. In that case, the mechanism may be expressed as a driving element (a moving punch), two driven elements (rocking beams, equipped with pairs of freely turning rollers), and an intermediate element (the blank, which is in contact with the punch and the beam's rollers). In this approach, the kinematic indeterminacy of the system in comparison with mechanisms that have rigid elements is determined by the continuous change in the elastic line of the intermediate element, characterized by variable length and changing stress–strain state at contact with the punch.

Consider the stage of press shaping in which the closest roller moves to the least distance from the punch surface. In kinematic study of the elements in the system, under the assumptions that the sheet is bent by the punch's surface with no intervening gap and the deformation of the sheet in the intermediate region (between the punch and the roller) is insignificant, we may obtain the angular and linear coordinates of the centers of curvature of the punch and roller profiles. The beam inclination ψ for the roller closest to the punch is related to the central angle β as follows

$$\psi = \arctan(h/g) - \beta. \quad (1)$$

The distance from the beam's tipping axis to the diametric plane of the punch is

$$Y_p = \frac{R_p + s + R_r + h - e\sin(\arctan(g/h) - \psi)}{\cos(\arctan(g/h) - \psi)}, \quad (2)$$

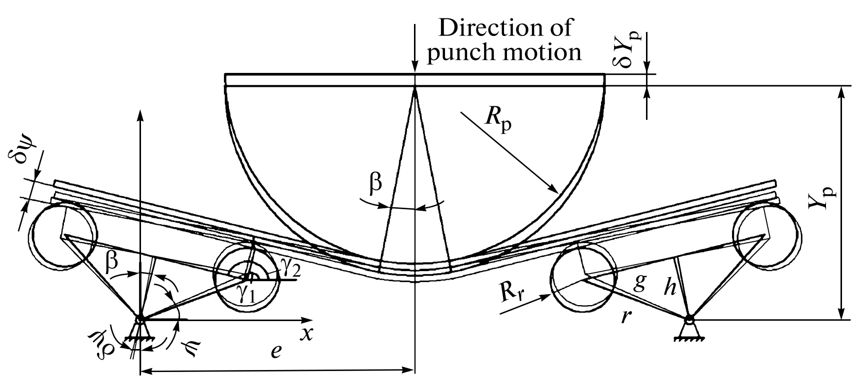

Fig. 1. Kinematic diagram of the press molding of a U-shaped blank.

while the coordinates corresponding to the axis of the roller closest to the punch are determined by the beam inclination: $x = r\cos\psi$, $y = r\sin\psi$. As a result, the central angle of the punch profile, determining the point of departure of the deformed sheet may be expressed in terms of Y_p as follows

$$\beta = \arctan(e/Y_p) - \mathrm{arctang}/(R_p + s + R_r + h). \quad (3)$$

In Fig. 1, we explain the notation employed in Eqs. (1)–(3).

The rigidity of the intermediate element is significantly less than that of the punch and rollers. Therefore, we must introduce corrections to take account of its deformation. One method of taking the elastoplastic properties of the intermediate element into account is to calculate its stress–strain state by the finite-element method. To take account of the strengthening of the element, we must introduce the condition of mechanical equilibrium of the beam, which markedly complicates the determination of the sheet's stress–strain state because an iterative procedure is required. However, if we take account of the strengthening, we may assess the stress state at sheet–punch contact. That permits the use of a simplified procedure to take account of the flexure of the contact section of the intermediate element and obtain a relation between the coordinates of the punch and rollers, in general form.

In the initial stage of shaping, we observe elastic deformation of the strip in the intermediate region (between the punch and the rollers). The force P from the rollers and the flexural stress at the point where the strip leaves the punch increase with increase in the punch coordinate Y_p and with increase in the flexure arm V, while the length L of the intermediate region is reduced. If we regard the strip as a cantilever beam attached to the punch and subject to the force from the closest roller, that force may be determined from the familiar equation

$$P = \frac{3EJV}{L^3}, \quad (4)$$

where V is the punch displacement; L is the length of the strip between the roller and the point of departure from the punch; and J is the moment of inertia of the sheet cross section (per unit length).

The variation in P is determined by Eq. (4) until the flexural stress reaches the yield point. Then the elastic deformation of the intermediate section of the strip (between the punch and the roller), where no shaping force acts, leads to additional rotation $\delta\psi$ of the beam and additional punch displacement $\delta Y_p = \delta Y_{p1} + \delta Y_{p2}$. The rotation of the beam determines correction δY_{p1}, while the strip flexure in the intermediate section (between the punch and the roller) determines δY_{p2}.

If we assume that the stress at the extreme point of strip–punch contact is equal to the yield point, taking

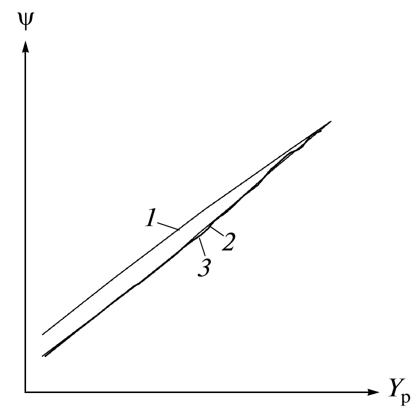

Fig. 2. Influence of the pliability of the sheet on the punch coordinate: (*1*) with variation in ψ; (*2*) with corrections for the actual elastoplastic properties of the sheet; (*3*) numerical solution by the finite-element method, with an iterative procedure.

account of strengthening, we may find the shaping force from the familiar formula

$$P = \frac{W_{xpl}\sigma_{me1}}{L}, \quad (5)$$

where $W_{xpl} = 0.25s^2$ for a section of unit length.

The additional beam rotation is equal to the rotation of the sheet cross section at the contact point with the roller closest to the punch, in case of elastic flexure, and may be determined in the form

$$\delta\psi = \frac{PL^2}{2EJ}. \quad (6)$$

With beam rotation by $\delta\psi$, the center of the roller is shifted by $r\delta\psi$, which corresponds to additional displacement of the punch and modification of Y_p by an amount δY_{p1}, where

$$\delta Y_{p1} = \frac{\delta\psi r\sin(\gamma_2 - \gamma_1)}{\sin(1.5\pi - \gamma_2)}. \quad (7)$$

The additional displacement δY_{p2} may be determined as

$$\delta Y_{p2} = \frac{s^2L^2\sigma_{me1}}{12EI\cos[0.5\pi - \psi + \delta\psi - \arctan(g/h)]}. \quad (8)$$

On the basis of the algorithm for calculating the intermediate coordinates of the tool and sheet, including Eqs. (1)–(8), we may write a computational program. Solution yields the functional relation between the punch coordinate Y_p and the beam inclination ψ, as well as the center coordinates of the rollers attached to the ends of the beam, with allowance for the elastoplastic properties of the intermediate element (the sheet).

In Fig. 2, for purposes of comparison, we show three graphs obtained for the same initial parameters:

(*1*) the variation in ψ as a function of the punch coordinate Y_p for an absolutely rigid intermediate element, according to Eqs. (1)–(3); (*2*) the results according to the algorithm with corrections for the actual elastoplastic properties of the sheet—that is, on the basis of Eqs. (4)–(8); (*3*) the numerical solution by the finite-element method, with an iterative procedure to account for the mechanical equilibrium of the beam.

The agreement of curves *2* and *3* means that, in subsequent calculations of the sheet's stress–strain state by numerical methods in plasticity theory, we may specify the coordinates of the tool's centers of curvature obtained on the basis of the corresponding program, with wide variation in the initial parameters of the tool and the sheet.

The proposed computational algorithm may be used for different types of tool motion in press shaping. In controlling the quality and precision of the product, the most important step is to determine the tool motion, with allowance for the elastoplastic properties of the deformed metal sheet.

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